

INTRODUCTION TO OPTICS

THIRD EDITION

Introduction to Optics is now available in a re-issued edition from Cambridge University Press. Designed to offer a comprehensive and engaging introduction to intermediate and upper-level undergraduate physics and engineering students, this text also allows instructors to select specialized content to suit individual curricular needs and goals.

Specific features of the text, in terms of coverage beyond traditional areas, include extensive use of matrices in dealing with ray tracing, polarization, and multiple thin-film interference; three chapters devoted to lasers; a separate chapter on the optics of the eye; and individual chapters on holography, coherence, fiber optics, interferometry, Fourier optics, nonlinear optics, and Fresnel equations.

FRANK L. PEDROTTI, S. J. (1932–2010) was a member of the Society of Jesus and served on the faculty at a number of institutions, including Marquette University, from 1977 to 1994. He received a Ph.D. in Physics from the University of Cincinnati in 1962. His research areas included solid state physics and laser optics and he taught and developed courses across the undergraduate curriculum. His course notes served as the basis for the first edition of the text *Introduction to Optics*, which he co-authored with his brother, Leno S. Pedrotti.

LENO M. PEDROTTI is a professor of Physics at the University of Dayton, where he joined the faculty in 1987, after completing his Ph.D. at the University of New Mexico in 1986. He has published papers on a variety of topics in theoretical quantum optics, including the quantum theory of the laser, microcavity lasers, nonclassical states of light, and atom/field/cavity interactions. He has taught courses that span the undergraduate physics curriculum, as well as selected graduate electro-optics courses.

LENO S. PEDROTTI (1927–2008) was a professor of Physics at the Air Force Institute of Technology (AFIT) and Chief Scientist and Senior Vice President at the Center for Occupational Research & Development (CORD). He earned a Ph.D. in Physics from the University of Cincinnati in 1961. He joined AFIT in 1951, where he served as chair of the Physics Department from 1964 to 1982. At CORD, he spearheaded the development of technical education materials for high-school and college students. His research areas included solid state physics and laser optics. He was a fellow of the Optical Society of America.

To our families and friends for their timely support during the preparation of this textbook.

INTRODUCTION TO OPTICS

THIRD EDITION

FRANK L. PEDROTTI
Deceased

LENO M. PEDROTTI
University of Dayton, Ohio

LENO S. PEDROTTI
Deceased



CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India
79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/9781108428262

DOI: 10.1017/9781108552493

© Cambridge University Press 2018

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

This book was previously published by Pearson Education, Inc.

Reissued by Cambridge University Press 2018

Printed in the United States of America by Sheridan Books, Inc., 2017

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data

ISBN 978-1-108-42826-2 Hardback

Additional resources for this publication at www.cambridge.org/pedrotti3ed

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Disclaimer: every effort has been made to secure necessary permissions to reproduce copyright material in this work, though in some cases it has proved impossible to trace copyright holders. If any omissions are brought to our notice, we will be happy to include appropriate acknowledgements in a subsequent edition.

Brief Contents

Physical Constants xii

Preface xiii

Part I

- 1 Nature of Light 1
- 2 Geometrical Optics 16
- 3 Optical Instrumentation 50
- 4 Wave Equations 94
- 5 Superposition of Waves 113
- 6 Properties of Lasers 131
- 7 Interference of Light 163
- 8 Optical Interferometry 192
- 9 Coherence 224
- 10 Fiber Optics 243
- 11 Fraunhofer Diffraction 267
- 12 The Diffraction Grating 292
- 13 Fresnel Diffraction 308
- 14 Matrix Treatment of Polarization 333
- 15 Production of Polarized Light 350

Part II

- 16 Holography 372
 - 17 Optical Detectors and Displays 386
 - 18 Matrix Methods in Paraxial Optics 396
 - 19 Optics of the Eye 419
 - 20 Aberration Theory 438
 - 21 Fourier Optics 458
 - 22 Theory of Multilayer Films 476
 - 23 Fresnel Equations 491
 - 24 Nonlinear Optics and the Modulation of Light 510
 - 25 Optical Properties of Materials 535
 - 26 Laser Operation 549
 - 27 Characteristics of Laser Beams 582
 - 28 Selected Modern Applications 607
- References R-1
- Answers to Selected Problems A-1
- Index I-1

Contents

Physical Constants xii

Preface xiii

Part I

1 Nature of Light 1

Introduction 1

1-1 A Brief History 2

1-2 Particles and Photons 4

1-3 The Electromagnetic Spectrum 6

1-4 Radiometry 11

Problems 15

2 Geometrical Optics 16

Introduction 16

2-1 Huygens' Principle 17

2-2 Fermat's Principle 20

2-3 Principle of Reversibility 22

2-4 Reflection in Plane Mirrors 22

2-5 Refraction Through Plane Surfaces 23

2-6 Imaging by an Optical System 25

2-7 Reflection at a Spherical Surface 27

2-8 Refraction at a Spherical Surface 32

2-9 Thin Lenses 35

2-10 Vergence and Refractive Power 39

2-11 Newtonian Equation for the Thin Lens 42

2-12 Cylindrical Lenses 42

Problems 46

3 Optical Instrumentation 50

- Introduction 50
- 3-1** Stops, Pupils, and Windows 50
- 3-2** A Brief Look at Aberrations 58
- 3-3** Prisms 60
- 3-4** The Camera 69
- 3-5** Simple Magnifiers and Eyepieces 75
- 3-6** Microscopes 79
- 3-7** Telescopes 82
- Problems 89

4 Wave Equations 94

- Introduction 94
- 4-1** One-Dimensional Wave Equation 94
- 4-2** Harmonic Waves 96
- 4-3** Complex Numbers 99
- 4-4** Harmonic Waves as Complex Functions 100
- 4-5** Plane Waves 100
- 4-6** Spherical Waves 102
- 4-7** Other Harmonic Waveforms 103
- 4-8** Electromagnetic Waves 104
- 4-9** Light Polarization 108
- 4-10** Doppler Effect 110
- Problems 111

5 Superposition of Waves 113

- Introduction 113
- 5-1** Superposition Principle 113
- 5-2** Superposition of Waves of the Same Frequency 114
- 5-3** Random and Coherent Sources 119
- 5-4** Standing Waves 120
- 5-5** The Beat Phenomenon 123
- 5-6** Phase and Group Velocities 125
- Problems 129

6 Properties of Lasers 131

- Introduction 131
- 6-1** Energy Quantization in Light and Matter 132
- 6-2** Thermal Equilibrium and Blackbody Radiation 135
- 6-3** Nonlaser Sources of Electromagnetic Radiation 138
- 6-4** Einstein's Theory of Light-Matter Interaction 143
- 6-5** Essential Elements of a Laser 146
- 6-6** Simplified Description of Laser Operation 149
- 6-7** Characteristics of Laser Light 153
- 6-8** Laser Types and Parameters 158
- Problems 161

7 Interference of Light 163

- Introduction 163
- 7-1** Two-Beam Interference 163
- 7-2** Young's Double-Slit Experiment 169
- 7-3** Double-Slit Interference with Virtual Sources 173
- 7-4** Interference in Dielectric Films 175
- 7-5** Fringes of Equal Thickness 180
- 7-6** Newton's Rings 181
- 7-7** Film-Thickness Measurement by Interference 182
- 7-8** Stokes Relations 184
- 7-9** Multiple-Beam Interference in a Parallel Plate 185
- Problems 189

8 Optical Interferometry 192

- Introduction 192
- 8-1** The Michelson Interferometer 193
- 8-2** Applications of the Michelson Interferometer 196
- 8-3** Variations of the Michelson Interferometer 198
- 8-4** The Fabry-Perot Interferometer 199
- 8-5** Fabry-Perot Transmission: The Airy Function 201
- 8-6** Scanning Fabry-Perot Interferometer 206
- 8-7** Variable-Input-Frequency Fabry-Perot Interferometers 211
- 8-8** Lasers and the Fabry-Perot Cavity 213
- 8-9** Fabry-Perot Figures of Merit 216
- 8-10** Gravitational Wave Detectors 217
- Problems 220

9 Coherence 224

- Introduction 224
- 9-1** Fourier Analysis 224
- 9-2** Fourier Analysis of a Finite Harmonic Wave Train 228
- 9-3** Temporal Coherence and Line Width 230
- 9-4** Partial Coherence 231
- 9-5** Spatial Coherence 237
- 9-6** Spatial Coherence Width 238
- Problems 241

10 Fiber Optics 243

- Introduction 243
- 10-1** Applications 243
- 10-2** Communications System Overview 244
- 10-3** Bandwidth and Data Rate 246
- 10-4** Optics of Propagation 246
- 10-5** Allowed Modes 249
- 10-6** Attenuation 251
- 10-7** Distortion 253
- 10-8** High-Bit-Rate Optical-Fiber Communications 260
- Problems 264

11 Fraunhofer Diffraction 267

- Introduction 267
- 11-1** Diffraction from a Single Slit 268
- 11-2** Beam Spreading 273
- 11-3** Rectangular and Circular Apertures 274
- 11-4** Resolution 279
- 11-5** Double-Slit Diffraction 281
- 11-6** Diffraction from Many Slits 284
- Problems 289

12 The Diffraction Grating 292

- Introduction 292
- 12-1** The Grating Equation 292
- 12-2** Free Spectral Range of a Grating 293
- 12-3** Dispersion of a Grating 295
- 12-4** Resolution of a Grating 296
- 12-5** Types of Gratings 298
- 12-6** Blazed Gratings 299
- 12-7** Grating Replicas 301
- 12-8** Interference Gratings 302
- 12-9** Grating Instruments 303
- Problems 305

13 Fresnel Diffraction 308

- Introduction 308
- 13-1** Fresnel-Kirchhoff Diffraction Integral 308
- 13-2** Criterion for Fresnel Diffraction 311
- 13-3** The Obliquity Factor 312
- 13-4** Fresnel Diffraction from Circular Apertures 312
- 13-5** Phase Shift of the Diffracted Light 316
- 13-6** The Fresnel Zone Plate 316
- 13-7** Fresnel Diffraction from Apertures with Rectangular Symmetry 318
- 13-8** The Cornu Spiral 320
- 13-9** Applications of the Cornu Spiral 324
- 13-10** Babinet's Principle 330
- Problems 331

14 Matrix Treatment of Polarization 333

- Introduction 333
- 14-1** Mathematical Representation of Polarized Light: Jones Vectors 334
- 14-2** Mathematical Representation of Polarizers: Jones Matrices 341
- Problems 347

15 Production of Polarized Light 350

- Introduction 350
- 15-1** Dichroism: Polarization by Selective Absorption 350
- 15-2** Polarization by Reflection from Dielectric Surfaces 353
- 15-3** Polarization by Scattering 355
- 15-4** Birefringence: Polarization with Two Refractive Indices 357
- 15-5** Double Refraction 361
- 15-6** Optical Activity 363
- 15-7** Photoelasticity 367
- Problems 369

Part II

16 Holography 372

- Introduction 372
- 16-1 Conventional Versus Holographic Photography 372
- 16-2 Hologram of a Point Source 373
- 16-3 Hologram of an Extended Object 375
- 16-4 Hologram Properties 379
- 16-5 White-Light (Rainbow) Holograms 379
- 16-6 Other Applications of Holography 381
- Problems 384

17 Optical Detectors and Displays 386

- Introduction 386
- 17-1 Thermal Detectors of Radiation 386
- 17-2 Quantum Detectors of Radiation 387
- 17-3 Image Detection 389
- 17-4 Optical Detectors: Noise and Sensitivity 390
- 17-5 Optical Displays 391
- Problems 394

18 Matrix Methods in Paraxial Optics 396

- Introduction 396
- 18-1 The Thick Lens 396
- 18-2 The Matrix Method 399
- 18-3 The Translation Matrix 400
- 18-4 The Refraction Matrix 400
- 18-5 The Reflection Matrix 401
- 18-6 Thick-Lens and Thin-Lens Matrices 402
- 18-7 System Ray-Transfer Matrix 404
- 18-8 Significance of System Matrix Elements 406
- 18-9 Location of Cardinal Points for an Optical System 408
- 18-10 Examples Using the System Matrix and Cardinal Points 410
- 18-11 Ray Tracing 412
- Problems 416

19 Optics of the Eye 419

- Introduction 419
- 19-1 Biological Structure of the Eye 419
- 19-2 Photometry 421
- 19-3 Optical Representation of the Eye 424
- 19-4 Functions of the Eye 425
- 19-5 Vision Correction with External Lenses 428
- 19-6 Surgical Vision Correction 434
- Problems 436

20 Aberration Theory 438

- Introduction 438
- 20-1** Ray and Wave Aberrations 439
- 20-2** Third-Order Treatment of Refraction at a Spherical Interface 440
- 20-3** Spherical Aberration 444
- 20-4** Coma 447
- 20-5** Astigmatism and Curvature of Field 449
- 20-6** Distortion 451
- 20-7** Chromatic Aberration 451
- Problems 456

21 Fourier Optics 458

- Introduction 458
- 21-1** Optical Data Imaging and Processing 459
- 21-2** Fourier-Transform Spectroscopy 471
- Problems 474

22 Theory of Multilayer Films 476

- Introduction 476
- 22-1** Transfer Matrix 477
- 22-2** Reflectance at Normal Incidence 481
- 22-3** Two-Layer Antireflecting Films 483
- 22-4** Three-Layer Antireflecting Films 486
- 22-5** High-Reflectance Layers 486
- Problems 489

23 Fresnel Equations 491

- Introduction 491
- 23-1** The Fresnel Equations 491
- 23-2** External and Internal Reflections 497
- 23-3** Phase Changes on Reflection 499
- 23-4** Conservation of Energy 502
- 23-5** Evanescent Waves 504
- 23-6** Complex Refractive Index 506
- 23-7** Reflection from Metals 507
- Problems 508

24 Nonlinear Optics and the Modulation of Light 510

- Introduction 510
- 24-1** The Nonlinear Medium 511
- 24-2** Second Harmonic Generation and Frequency Mixing 513
- 24-3** Electro-optic Effects 517
- 24-4** The Faraday Effect 524
- 24-5** The Acousto-optic Effect 526
- 24-6** Optical Phase Conjugation 529
- 24-7** Optical Nonlinearities in Fibers 531
- Problems 533

25 Optical Properties of Materials 535

- Introduction 535
- 25-1** Polarization of a Dielectric Medium 535
- 25-2** Propagation of Light Waves in a Dielectric 539
- 25-3** Conduction Current in a Metal 544
- 25-4** Propagation of Light Waves in a Metal 544
- 25-5** Skin Depth 545
- 25-6** Plasma Frequency 546
- Problems 548

26 Laser Operation 549

- Introduction 549
- 26-1** Rate Equations 549
- 26-2** Absorption 553
- 26-3** Gain Media 557
- 26-4** Steady-State Laser Output 561
- 26-5** Homogeneous Broadening 564
- 26-6** Inhomogeneous Broadening 567
- 26-7** Time-Dependent Phenomena 569
- 26-8** Pulsed Operation 571
- 26-9** Some Important Laser Systems 575
- 26-10** Diode Lasers 577
- Problems 579

27 Characteristics of Laser Beams 582

- Introduction 582
- 27-1** Three-Dimensional Wave Equation and Electromagnetic Waves 582
- 27-2** Gaussian Beams 583
- 27-3** Spot Size and Radius of Curvature of a Gaussian Beam 586
- 27-4** Characteristics of Gaussian Beams 587
- 27-5** Modes of Spherical Mirror Cavities 591
- 27-6** Laser Propagation Through Arbitrary Optical Systems 593
- 27-7** Higher-Order Gaussian Beams 600
- Problems 605

28 Selected Modern Applications 607

- Introduction 607
- 28-1** Overview of Laser Applications 607
- 28-2** Lasers in Medicine 608
- 28-3** Remote Sensing 612
- 28-4** Ultrashort Pulse Production and Applications 613
- 28-5** Laser Cooling and Trapping 615
- 28-6** Optical Parametric Oscillators 617
- 28-7** Near-Field Microscopy 620
- Problems 621

References R-1**Answers to Selected Problems A-1****Index I-1**

Physical Constants

Speed of light	$c = 2.998 \times 10^8 \text{ m/s}$
Electron charge	$e = 1.602 \times 10^{-19} \text{ C}$
Electron rest-mass	$m = 9.109 \times 10^{-31} \text{ kg}$
Planck constant	$h = 6.626 \times 10^{-34} \text{ J-s}$
Boltzmann constant	$k = 1.3805 \times 10^{-23} \text{ J/K}$
Permittivity of vacuum	$\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2/\text{N-m}^2$
Permeability of vacuum	$\mu_0 = 4\pi \times 10^{-7} \text{ T-m/A}$

Preface

INTRODUCTION

The field of optics impacts an ever-expanding range of applications in physics, engineering, and technology. The parallel emergence of lasers, fiber optics, nonlinear devices, and a variety of semiconductor sources and detectors in the 1960s initiated a continuing period of rapid development in applied and theoretical optics. The need for a variety of updated optics texts with different approaches and emphases is apparent, both for students of optics and for practitioners who need an occasional review of the basics.

With *Introduction to Optics* we propose to teach introductory modern optics at an intermediate level. In order to use this text, students should have a preparatory background that includes a calculus-based introductory physics sequence and at least two semesters of calculus. The material in this text encompasses the traditional areas of classical optics and many topics in modern optics. The organization of the material in this text is intended to facilitate its use in a variety of one-semester courses, with different emphases. In addition, the text includes more than enough material to be used in a full-year optics course for physics or engineering students at the sophomore, junior, or senior undergraduate level.

Specific features of the text, in terms of coverage beyond traditional areas, include extensive use of 2×2 matrices in dealing with ray tracing, polarization, and multiple thin-film interference; three chapters devoted to lasers; a separate chapter on the optics of the eye; and individual chapters on holography, coherence, fiber optics, interferometry, Fourier optics, nonlinear optics, and Fresnel equations. We have organized the text into two parts. Part I includes chapters that form the basis of a typical one-semester optics course designed for sophomore or junior physics majors. Chapters in Part I are designed to be covered in sequence, although subsets of these chapters can be omitted to suit specific curricular needs. Part II contains chapters that are

largely self-contained and, upon completion of a subset of chapters in Part I, can be covered in a variety of sequences. We hope that this organization will allow teachers to select specialized content to suit individual curricular needs. Possible orderings of chapter coverage appropriate for several possible optics courses with different emphases are provided later in this Preface.

IMPROVEMENTS IN THE THIRD EDITION

The Third Edition of this text differs from the Second Edition in that several topics have been added or expanded and the order of presentation of the material has been changed to provide teachers with greater freedom to tailor the text to meet specific curricular requirements. New features of the Third Edition include the following:

- The treatment of wave equations (Chapter 4) has been expanded with the addition of qualitative descriptions of cylindrical and Gaussian beams and a brief introduction to light polarization.
- The coverage of optical interferometry (Chapter 8) has been expanded by providing a more detailed description of the operation and applications of the Fabry-Perot interferometer and by adding a description of gravitational wave detectors.
- New descriptions of other modern optics applications appear throughout the text. For example, we have added a section on wavelength-division-multiplexing in fiber communication systems in Chapter 10 and we have added sections on liquid-crystal displays and plasma displays in Chapter 17.
- A new chapter (Chapter 26, “Laser Operation”) provides both a *quantitative*, rate-equation treatment of laser operation and a qualitative introduction to the semiconductor laser. The four chapters—Chapter 6, “Properties of Lasers,” Chapter 26, “Laser Operation,” Chapter 27, “Characteristics of Laser Beams,” and Chapter 28, “Selected Modern Applications,”—taken together constitute a rather comprehensive introduction to laser optics for undergraduates.
- Based on extensive reviewer feedback we have carefully revised each chapter, sharpening and clarifying discussions and mathematical developments throughout.
- Chapter 28, an expansion and revision of the Second Edition chapter “Laser Applications,” includes new sections describing ultrashort pulse production, laser cooling and trapping, optical parametric oscillators, and near-field microscopy.
- More than 100 problems have been added.
- For Instructors, we once again offer an Instructor’s Solutions Manual (0-13-173918-2) containing fully worked-out solutions to all end-of-chapter problems. Instructors can also visit the *Introduction to Optics, 3rd Edition* information page on Prentice Hall’s online catalog (www.prenhall.com <www.prenhall.com>) to download additional instructor resources, including electronic versions of the figures from *Introduction to Optics, 3rd Edition*.

Nearly all of the material from the Second Edition remains in the Third Edition. We have sharpened and clarified discussions and mathematical discussions throughout.

TEXT ORGANIZATION

The text is divided into two parts. The individual chapters in Part II primarily rely only on material covered in Part I and so can be covered in a variety of different sequences. As an indication of the flexibility of the text, we offer four possible one-semester course organizations.

Traditional “Balanced” Optics Course

Prerequisites: Two or three semesters of introductory physics and two semesters of calculus

Chapter 1 Nature of Light
 Chapter 2 Geometrical Optics
 Chapter 3 Optical Instrumentation
 Chapter 4 Wave Equations
 Chapter 5 Superposition of Waves
 Chapter 6 Properties of Lasers
 Chapter 7 Interference of Light
 Chapter 8 Optical Interferometry
 Chapter 9 Coherence
 Chapter 10 Fiber Optics
 Chapter 11 Fraunhofer Diffraction
 Chapter 13 Fresnel Diffraction
 Chapter 15 Production of Polarized Light

Physical Optics

Prerequisites: Two or three semesters of introductory physics, two semesters of calculus, and one semester of intermediate electromagnetics

Chapter 1 Nature of Light
 Chapter 4 Wave Equations
 Chapter 5 Superposition of Waves
 Chapter 6 Properties of Lasers
 Chapter 7 Interference of Light
 Chapter 8 Optical Interferometry
 Chapter 9 Coherence
 Chapter 11 Fraunhofer Diffraction
 Chapter 12 The Diffraction Grating
 Chapter 13 Fresnel Diffraction
 Chapter 14 Matrix Treatment of Polarization
 Chapter 15 Production of Polarized Light
 Chapter 16 Holography
 Chapter 21 Fourier Optics

Traditional Course: Geometrical Optics Emphasis

Prerequisites: Two or three semesters of introductory physics and two semesters of calculus

Chapter 1 Nature of Light
 Chapter 2 Geometrical Optics
 Chapter 3 Optical Instrumentation
 Chapter 18 Matrix Methods in Paraxial Optics
 Chapter 19 Optics of the Eye
 Chapter 20 Aberration Theory
 Chapter 4 Wave Equations
 Chapter 5 Superposition of Waves
 Chapter 6 Properties of Lasers
 Chapter 7 Interference of Light
 Chapter 8 Optical Interferometry
 Chapter 10 Fiber Optics

Laser Optics

Prerequisites: Two or three semesters of introductory physics, two semesters of calculus, and one semester of intermediate electromagnetics

Chapter 4 Wave Equations
 Chapter 5 Superposition of Waves
 Chapter 6 Properties of Lasers
 Chapter 26 Laser Operation
 Chapter 7 Interference of Light
 Chapter 8 Optical Interferometry
 Chapter 9 Coherence
 Chapter 10 Fiber Optics
 Chapter 11 Fraunhofer Diffraction
 Chapter 14 Matrix Treatment of Polarization
 Chapter 15 Production of Polarized Light
 Chapter 18 Matrix Methods in Paraxial Optics
 Chapter 27 Characteristics of Laser Beams
 Chapter 28 Selected Modern Applications

Other chapter sequences are, of course, possible. For example, for advanced undergraduates with two semesters of electromagnetic theory, the Laser Optics course could be altered by replacing Chapters 4, 5, and 7 with Chapters 16 (“Holography”), 22 (“Theory of Multilayer Films”), and 24 (“Nonlinear Optics and the Modulation of Light”). A variety of two-semester, two-quarter, or three-quarter sequences are also possible.

ACKNOWLEDGMENTS

We wish to thank the many teachers who have inspired us with an interest in optics and teaching, and the many students who have motivated us to teach with clarity and efficiency.

First and Second Edition

For their very helpful reading of portions of the manuscript for the First Edition, we are indebted to Hugo Weichel, James Tucci, Hajime Sakai, Arthur H. Guenther, and Thomas B. Greenslade. For their suggestions leading to the Second Edition we wish to thank the team of reviewers selected by Prentice Hall: Joel Blatt, Florida Institute of Technology; James Boger, Oregon Institute of Technology; Harry Daw, New Mexico State University; Edward Eyler, University of Delaware; and Daniel Wilkins, University of Nebraska. For his review and suggestions in the chapter on the eye, we are also pleased to acknowledge and thank Dr. Michael Pedrotti, O.D. We also wish to thank Judy Lawson, COD, for her sketch of Einstein that graces page 1.

Third Edition

Many of the changes made in the Third Edition of the book grew in part from the thoughtful suggestions made by the reviewers: Ralph Alexander, University of Missouri at Rolla; Ramendra Bahuguna, San Jose State University; Robert M. Bunch, Rose-Hulman Institute of Technology; Henry J. Leckenby, Texas A&M, Kingsville; Peter G. LoPresti, University of Tulsa; Sergey Mirov, University of Alabama, Birmingham; B. Paul Padley, Rice University; Jie Shan, Case Western University; John E. Sohl, Weber State University; Rick Trebino, Georgia Tech; and Paul Voytas, Wittenberg University. We are deeply indebted to this group of reviewers for their valuable suggestions. From this group we wish to extend special thanks to John Sohl and Robert Bunch for their careful reading of the entire Third Edition. We would also like to thank Robert Brecha, Bruce Craver, and Peter Powers from the University of Dayton for suggestions and advice leading to some of the new material in the Third Edition and Mark Whitney and Kathy Kral of COD for artistic and logistical help.

Finally, we express our gratitude to the editorial and production staff of Prentice Hall for their enthusiastic and professional support. In particular, we are indebted to our acquisitions editors, Holly Hodder for the First Edition, Ray Henderson for the Second Edition, and Erik Fahlgren for the Third Edition, and to our production editors, Kathleen Lafferty for the first two editions and Kevin Bradley and Cindy Miller (of GGS Book Services) for the Third Edition. All efforts were made to ensure accuracy, but responsibility for all errors lie with authors.

Frank L. Pedrotti, S.J.
Leno S. Pedrotti
Leno M. Pedrotti